NSG-154

Environmental Impoverishment, Social Isolation and Changes in Brain Chemistry and Anatomy[1,2]

David Krech, Mark R. Rosenzweig and Edward L. Bennett

University of California, Berkeley

Address: Department of Psychology
3210 Tolman Hall
University of California
Berkeley, California, 94720

Running Head: Impoverished environment and cerebral changes

Abstract

A series of experiments, employing a littermate control design, was performed with rats of the Berkeley S_1 strain to answer three questions: (a) What brain effects will be produced by more stringent impoverishment than was employed in former experiments? (b) Will housing animals in pairs in an impoverished environment protect them from the usual cerebral consequences of isolation in an impoverished environment? (c) Is an impoverished environment, with or without isolation, a stressor? Two hundred and sixty-five animals were assigned among four conditons: Environmental complexity and training, social control, isolated in extreme impoverishment, or paired in extreme impoverishment. Some of the largest differences among groups occurred in the ratio of cholinesterase to acetylcholinesterase activity in the cortex. The results demonstrate that (a) the more restricted is the environment, the greater the changes in brain chemistry and anatomy, (b) pairing animals did not protect them from developing cerebral changes similar to those of animals isolated in impoverishment, and (c) there were no indications that isolation or impoverishment are stressors.

Indexing terms: Acetylcholinesterase, Adrenal gland weight, Brain anatomy, Brain chemistry, Brain weight, Cerebral cortex, Cholinesterase, Early experience, Hexokinase, Isolation Stress, S_1 strain of rats, Somesthetic cortex, Visual cortex.

In previous experiments we have shown consistent and significant differences in brain anatomy and chemistry between rats raised in groups in experientially enriched environments and their littermates raised in isolation in impoverished environments. The main anatomical differences have been in weight of cerebral tissue, depth of cerebral cortex and glial/neural ratio; the principal chemical differences, in activities of acetylcholinesterase and cholinesterase (1,3,4). In the series of experiments reported here we have attempted to answer three questions: (a) What brain effects will be produced by more stringent impoverishment than was employed in former experiments? (b) Will housing animals in pairs in an impoverished environment protect them from the usual cerebral consequences of living in isolation in an impoverished environment? (c) Can an impoverished environment, with or without isolation, be considered as a stressor?

METHODS

Behavioral Procedures

The two experiments described here in detail were conducted at the Space Sciences Laboratory of the University of California. In addition we will have recourse to both published and unpublished data from a number of experiments done in the Berkeley psychological laboratories.

For the Space Sciences experiments, littermate male rats of the Berkeley S_1 line were assigned to the following conditions at weaning (about 25 days of age) and were kept there for about 80 days:

(a) Environmental Complexity and Training (ECT). Here the animals were housed in groups of 11 or 12 in a large cage provided with "toys." Each day they were permitted exploration in a field with barriers, and from the age of

about 60 days they were trained in a series of maze and visual discrimination problems. The ECT condition has been described in detail previously (7).

(b) Social Control (SC). These animals were housed three to a cage under our standard colony conditions (7). The SC condition was employed in Experiment 2 but not in Experiment 1.

(c) Isolated in Extreme Impoverishment (IEI). These animals were individually housed under stringently impoverished conditions--an intensification of our standard environmentally impoverished condition. IEI animals were limited in their contact with the external environment by a series of measures: Each animal was housed individually in a cage suspended in a box lined with glass wool padding 2.5 cm thick and closed on all sides except the front. The cages were 20 cm high, 20 cm wide, and 28 cm deep; the inside dimensions of the padded boxes were 46 cm high, 36 cm wide, and 89 cm deep. Each cage hung 4 cm below the padding at the top of the box, and the front of the cage was 53 cm behind the front of the box. The fronts of the cages were opaque, so the experimenters could fill the hoppers and water bottles without being seen by the rats. (In our standard isolation conditions, the cage door had to be opened a few times a week to replenish the supply of pellets, and the rat could see the experimenter when the water bottles were changed.) The sides and bottoms of the IEI cages were made of bars, and excrement fell to a pan which could be removed for cleaning without handling the animal. The boxes were placed in a sound-insulated room (Industrial Acoustics Co., Model 404-A Audiometric Room) which attenuates external noise by about 55 db. The ambient noise in the room was about 50 db re .0002 dynes per sq. cm. The room was lighted by two 40-W bulbs on a 12-hr. light - 12-hr. dark schedule. Temperature was maintained at 24° C $\pm 2^{\circ}$.

(d) Paired in Extreme Impoverishment (PEI). This condition was the same as c above except that two animals, from different litters, were placed in each cage.

In all four conditions, animals had food (Simonsen Laboratory maintenance diet pellets) and water ad libidum. They were weighed about once a week. In Experiment 1, littermate animals were placed in conditions a, c, and d in January, 1964; in Experiment 2, littermates were placed in all four conditions in April, 1964.

Anatomical and Chemical Procedures

At the end of the 80-day behavioral phase, all animals were sacrificed under code numbers that did not reveal their experimental treatment. The brains were dissected into five samples--visual cortex, somesthetic cortex, remaining dorsal cortex, ventral cortex and associated tissue, and the rest of the brain (subcortex II). The methods of dissection have been described in detail previously (8). The samples were weighed, frozen quickly on dry ice and stored at -20°C for enzyme analysis. The adrenal glands were removed and weighed at the same time.

Activities of both acetylcholinesterase (AChE) and cholinesterase (ChE) were measured. The analyses were done colorimetrically, employing acetylthiocholine as the substrate for AChE. For the ChE analyses, AChE activity was inhibited by BW 284c51, a specific inhibitor, and butyrylthiocholine was employed as the substrate. (A detailed description of the procedures is available upon request from the authors.) Hexokinase activity was also measured in Experiment 1 by a method described previously (2).

RESULTS

Brain Weights

Table 1 presents a summary of the brain weight data. To conserve space, the values for each group are given in terms of the percentage difference between the mean weight of the group in question and the mean weight of the Littermate IEI group, i.e., 100 ($\bar{X}$ ECT - $\bar{X}$ IEI)/ $\bar{X}$ IEI. Thus, in weight of the visual cortex sample, the enriched-environment (ECT) group exceeded the isolated impoverished (IEI) group by 9.8% ($P < .001$) in Experiment 1 and by 8.0% ($P < .01$) in Experiment 2; for the two experiments combined, the difference was 8.8% ($P < .001$). (The absolute values on which the percentages of Table 1 and the subsequent tables are based can be obtained from the authors.)

Insert Table 1 about here

In both experiments, the ECT group exceeded all other groups in mean weight of all brain samples, and most of these differences were statistically significant. The two impoverished groups (PEI and IEI) did not differ significantly from each other in any region.

The group living under colony conditions (SC) in Experiment 2 had weights closer to those of the IEI than to those of the ECT group in most brain measures. The SC brain weights differed significantly from the IEI values only for ventral cortex (4.6%, $P < .05$), total cortex, (4.3%, $P < .01$) and total brain (2.8%, $P < .05$). The greater brain weights of the enriched animals in comparison with their impoverished littermates cannot be explained in terms of body weight, as will be shown in the following section.

Terminal Body Weights

The littermate groups assigned to the different experimental conditions were almost identical in weight at the outset of each experiment, but at the end the individually impoverished group was the heaviest in both experiments. In the second experiment, the differences were sizeable; moreover, the more complex the environment, the lighter the terminal body weight. Overall, the impoverished groups were about 8% heavier than the enriched groups (see last row of Table 1). This replicates findings that animals in our previous isolation condition (IC) weighed about 7% more than their ECT littermates, presumably because ECT rats are more active while restricted-environment rats tend to be sedentary (1). Since the impoverished rats have heavier bodies but lighter brains than their enriched littermates, the differences between groups would have been larger if we had presented brain weight per unit of body weight rather than giving absolute weights.

Isolation Stress?

A syndrome of "isolation stress"--including aggressiveness, caudal dermatitis, increased weight of adrenals and thyroid, lighter spleen and thymus, and increased sensitivity to a poison, isoproterenol--has been described for the rat by Hatch et al. (5). It was concluded that this syndrome "indicates an endocrinopathy with hyperfunction of the adrenal cortex." Except for caging the animals singly, Hatch et al. did not attempt to reduce their contact with the laboratory environment; therefore "social isolation" could be considered the cause of "isolation stress." Other experimenters have not, however, found evidence of "isolation stress" (6).

We were unable to detect any signs of the "isolation stress" syndrome in the Berkeley S_1 strain. The IEI animals (which were more severely isolated than those of Hatch et al.) did not become aggressive; when weighed, they could be picked up

easily with bare hands. Nor did they develop caudal dermatitis. Sensitivity to isoproterenol was not determined because this would have been incompatible with the main purposes of the experiment. We did take one other measure that Hatch et al. used as an indicator of stress, the weight of the adrenal glands.

As can be seen in Table 1, the IEI animals developed significantly heavier adrenals than the ECTs--11.8% ($P < .05$). We doubt, however, that this can be taken as an indication of stress, for the following reasons. Adrenal weight varies with body weight (the average correlation being about .4 for the six sub-groups in the two experiments), and the IEI animals weighed 8.9% more than the ECT animals ($P < .001$). If adrenal weight is expressed as a fraction of body weight, then the ECT-IEI differences become nonsignificant. The adrenal weights of the paired impoverished rats do not differ from those of either the ECT or IEI groups, whether absolute or relative weights are taken. There is thus no evidence that an impoverished environment, with or without isolation, causes the S_1 strain to develop the syndrome described by Hatch et al.

Acetylcholinesterase Activity

Differences in AChE activity per unit of tissue weight between the IEI group and the other groups are given in Table 2. While the ECT animals exceeded their

---

Insert Table 2 about here

IEI littermates in weight of all brain sections, they are seen in Table 2 to have less AChE activity per unit of weight. In the cortex, this decrease in activity among the ECT animals is significant, for the two experiments combined, in all regions except the ventral cortex. The visual region, which showed relatively

large increases in weight, now shows the greatest decreases in enzymatic activity. Combining both experiments, the decrease amounts to 8.6% ($P < .00$). The remaining dorsal cortex, where the greatest ECT-IEI differences in weight occurred, shows differences in AChE activity less than half as large as those in the visual area. The differences between the ECT animals and the PEI rats are similar to those found between the ECT animals and the IEI rats. Thus, taking Experiments 1 and 2 together, the ECT rats show a 6.1% decrease in AChE activity in the visual cortex from that of the PEI rats ($P < .001$); a 3.9% decrease in the remaining dorsal cortex ($P < .05$); and a 2.6% decrease in total cortex ($P < .05$). These differences between the ECT and either the IEI or the PEI groups are similar to the usual findings with our standard ECT-IC design.

The PEI animals, of either experiment, do not differ from their IEI littermates on any measure of AChE activity except in the visual cortex. Thus in AChE activity, as in brain weight, the rats living in pairs in an impoverished environment do not differ from the rats living in isolation in an impoverished environment.

The animals living in colony conditions had AChE values that did not differ significantly from those of their ECT littermates in any brain region. They differed from the IEI values only at the visual cortex ($P < .01$).

Each of the decreases in AChE activity of the ECT group in Table 2 is smaller than the corresponding increase in tissue weight in Table 1. This means that the <u>total</u> activity of the enzyme (the activity taken without regard to tissue weight) is greater in the ECT than in the IEI animals. In some of the brain regions the increase in total AChE activity of the ECT over the IEI group attains statistical significance: remaining dorsal cortex, 5.7% ($P < .01$); total cortex, 3.1% ($P < .01$), and total brain, 2.0% ($P < .05$). The ECT animals even more consistently surpass

their PEI littermates in AChE activity: visual cortex, 4.6% ($P < .05$); somesthetic cortex, 3.9% ($P < .05$); total cortex, 2.7% ($P < .05$); rest of brain, 2.8% ($P < .05$), and total brain, 2.8% ($P < .01$). This increase in total AChE activity among the ECT rats over that of their impoverished littermates replicates our previous findings with the ECT and IC conditions. The two impoverished groups (living in pairs or in isolation) do not differ significantly in total AChE activity except in visual cortex where the IEI value is 4.3% greater ($P < .05$).

Cholinesterase Activity

In activity per unit of weight of the less specific enzyme ChE, the ECT animals exceeded the IEI animals by 1% or 2% in all cortical regions, but none of these differences was significant. Total activity of ChE in the cortex is clearly greater in the enriched than in either of the impoverished groups. The ECT animals exceed their IEI littermates by 11.4% in total ChE activity in the visual cortex ($P < .001$), by 6.7% in somesthetic cortex ($P < .01$), by 11.2% in remaining dorsal cortex ($P < .001$), by 3.8% in ventral cortex (N.S.), by 7.6% in total cortex ($P < .001$), and by 2.8% in the total brain ($P < .001$). The ECT groups showed as large and as significant differences in total ChE activity from the PEI as from the IEI groups, and the impoverished groups did not differ significantly from each other on any critical measure of total ChE activity. Thus the ChE differences among the enriched group and the two impoverished groups and between the individually isolated and the paired isolated groups follow our other measures as far as pattern is concerned: The enriched group differs from both the impoverished groups; the impoverished groups do not differ between themselves.

Ratios of Enzyme Activities

As we increase the number of different chemical compounds we can analyze in each sample, we also increase the number of revealing indicators of chemical

change accompanying differential experience. For example, measurement of both ChE and AChE activities allows us to compute the ratio of ChE activity to AChE activity for each tissue section of every animal. This ratio measure is independent of tissue weight, because weight, which enters into both assay ratio values, is cancelled out when the ratio is taken. Some of the principal results of this purely chemical comparison are shown in Table 3.

Insert Table 3 about here

The ECT animals exceed the IEI animals on this ratio measure throughout the cortex. In all cortical regions the ECT-IEI differences in the ChE/AChE ratio are larger than the differences in AChE activity per unit of weight (Table 2). Moreover, the chemical ratio differences between the ECT and IEI groups are significant in all cortical regions except the ventral cortex. In the rest of the brain, the ECT animals fall below the isolated animals, but not significantly so. In total brain, the groups do not differ significantly, unlike the case for AChE activity per unit of weight.

The ChE/AChE ratios show the ECT animals to be significantly greater than their PEI littermates in these regions: visual cortex, 6.8% ($P < .01$); remaining dorsal cortex, 5.2% ($P < .01$), and total cortex, 3.8% ($P < .01$). The only region in which the paired differ from the isolated impoverished animals is the visual cortex, 4.9% ($P < .05$).

The SC group did not differ significantly from the ECT group in the ChE/AChE ratio for any part of the brain. But the SC group did exceed both the IEI and the PEI groups in each part of the brain, and some of these differences were significant: In

the visual region, SC exceeded IEI by 14.5% ($P < .01$) and PEI by 10.1% ($P < .05$); in the somesthetic region, SC surpassed IEI by 6.8% ($P < .01$) and PEI by 4.2% ($P < .05$); in total cortex the ratio of the SC group was greater than that of the IEI group by 4.8% ($P < .05$). On most cortical measures the ChE/AChE ratio set the groups in the same order as the complexity of their experience--ECT, SC, PEI, IEI.

Thus the ChE/AChE ratio shows somewhat larger relative differences between groups than the other chemical measures and reveals the same pattern among groups--the enriched group differing significantly from both impoverished groups in most cortical regions, while the impoverished groups differ from each other in only a single region.

Hexokinase, which was measured in Experiment 1, did not differ significantly among the three groups in activity per unit of weight. In total activity of hexokinase, the ECT group was significantly greater than both the PEI and IEI groups for all brain regions except ventral cortex. We had previously found ECT to exceed IC littermates in total hexokinase activity throughout the cortex, and in just the same proportion that the ECT were superior in cortical weight (1). In the ratio of hexokinase to AChE activity, ECT exceeded IEI significantly at visual cortex (7.9%, $P < .001$). ECT exceeded PEI significantly at the visual area (5.8%, $P < .01$) and at the remaining dorsal cortex (5.4%, $P < .05$). The PEI and IEI groups did not differ significantly in the hexokinase/AChE ratio at any region. Thus, once more the ECT animals differ from both impoverished groups, while the impoverished groups do not differ from each other.

DISCUSSION

Effects of Varied Degrees of Impoverishment

How do the magnitudes of these ECT-IEI differences compare with differences found between ECT animals and littermates in other impoverished environments? (We have already seen that the ECT-PEI effects scarcely differ from the ECT-IEI effects.) We may compare the ECT-IEI effects with data from previous experiments where animals were raised in colony conditions (SC) and in impoverished conditions (IC) that were less stringent than the IEI conditions. The SC animals are somewhat impoverished, since they spend all their time in small cages with only two cagemates and have no opportunity to explore new territory nor any formal problems to solve. A further degree of impoverishment is realized in our IC condition where animals live singly under reduced stimulation (7). We have conducted three experiments (other than the present Experiment 2) in which littermates were assigned to the ECT or SC conditions. These three experiments included sets of brothers from each of 34 litters of S_1 rats. In six other experiments, 64 pairs of littermates were assigned to the ECT or IC conditions. Combining these with the Space Sciences experiments we then have data of 242 S_1 rats from eleven experiments for comparing the magnitudes of cortical effects of three degrees of environmental deprivation: SC vs. ECT (3 experiments), IC vs. ECT (6 experiments), and IEI vs. ECT (2 experiments). Figure 1 presents the results. Separate graphs are given for the visual area (the region most sensitive to environmental influences) and for the total cortex; in each graph results are shown for both tissue weight and AChE activity per unit of weight.

Figure 1 reveals an increase in the magnitude of the effects as the deprivation progresses from mild at the left (SC) to severe at the right (IEI). The progressive increase in size of effects holds for both tissue weight and AChE activity.

Insert Figure 1 about here

The two end-point of this progression (SC/ECT and IEI/ECT) differ from each other significantly on every measure. SC/ECT differs from IEI/ECT at beyond the .001 level for AChE activity of visual cortex, and beyond the .01 level for each of the three other measures in Fig. 1.

Impoverishment or Isolation?

What are the relative roles of environmental impoverishment and social isolation in causing the cerebral differences between the IEI and ECT groups? In our past experiments these variables have been confounded. The present experiments were designed to separate these two factors, and the results indicate clearly that environmental impoverishment, rather than social isolation, is the main cause of the IEI-ECT cerebral effects. The fact that the IEI and PEI groups do not differ significantly from each other on most measures, while they both differ significantly from their environmentally enriched littermates, demonstrates that the social stimulation provided by one companion cannot ward off the cerebral effects of an otherwise impoverished environment. The only suggestion of a significant difference between PEI and IEI groups occurred in the visual cortex for AChE activity and for the ChE/AChE ratio; even here Experiment 1 showed essentially no difference, and the level of significance for the two experiments combined was only at the .05 level. The visual cortex is the region most sensitive to the effects of

experience, and only here is there a hint that paired living may provide enough environmental enrichment to protect the animal, in some degree, from the cerebral effects of impoverishment. In other experiments now in progress we are attempting to distinguish between social and environmental factors when as many as twelve rats are caged together.

SUMMARY

Experiments were performed with littermate S_1 rats kept in one of four conditions: Environmental complexity and training, social control, isolated in extreme impoverishment, or paired in extreme impoverishment. Some of the largest differences among groups occurred in the ratio of ChE to AChE activity in the cortex. The results, taken with those of related experiments, demonstrate that the more restricted is the environment, the more brain chemistry and anatomy depart from those of littermates in an enriched situation. Pairing animals in the impoverished environment did not protect them from developing cerebral changes similar to those of animals isolated in impoverishment. There were no indications that either the isolation or the impoverishment is a stressor.

References

1. Bennett, E. L., M. C. Diamond, D. Krech, & M. R. Rosenzweig, Chemical and anatomical plasticity of brain. Science, 146, 610-619, 1964.

2. Bennett, E. L., J. B. Drori, D. Krech, M. R. Rosenzweig, & S. Abraham. Hexokinase activity in brain. J. biol. Chem., 237, 1758-1762, 1962.

3. Bennett, E. L., D. Krech, & M. R. Rosenzweig. Reliability and regional specificity of cerebral effects of environmental complexity and training. J. comp. physiol. Psychol., 57, 440-441, 1964.

4. Diamond, M. C., D. Krech, & M. R. Rosenzweig. The effects of an enriched environment on the histology of the rat cerebral cortex. J. comp. Neurol., 123, 111-119, 1964.

5. Hatch, A., T. Balazs, G. S. Wiberg, & H. C. Grice. Long-term isolation stress in rats. Science, 142, 507, 1963.

6. Jewett, R. E., & S. Norton. Measurement of behavior of rats under isolation and observations on preliminary drug effects. Psychopharmacologia, 6, 151-153, 1964.

7. Krech, D., M. R. Rosenzweig, & E. L. Bennett. Effects of environmental complexity and training on brain chemistry. J. comp. physiol. Psychol., 53, 509-519, 1960.

8. Rosenzweig, M. R., D. Krech, E. L. Bennett, & M. C. Diamond. Effects of environmental complexity and training on brain chemistry and anatomy: a replication and extension. J. comp. physiol. Psychol., 55, 429-437, 1962.

Footnotes

1. The main experiments in this paper were supported by NASA grant NsG 154-61 to Samuel Silver, Director of the Space Science Laboratory, University of California. The research also received help from the U.S. AEC.

2. We wish to acknowledge the help of Frank Harris in the behavioral procedures; Marie Hebert, Hiromi Morimoto and Barbara Olton in the chemical analyses; Carol Saslow, Carol Poe and Carroll Greene in the statistical analyses.

Table 1

Differences in Weights of Brain Sections, Adrenal Glands and Whole Body between Rats in Three Environments, and those of Littermates Isolated in Extreme Impoverishment (IEI)

(Expressed in percentages of the IEI values)

	Exper. 1		Exper. 2			1 & 2	
	ECT[a]	PEI[b]	ECT[a]	PEI[b]	SC[c]	ECT[a]	PEI[b]
Brain N	12	12	11	11	11	23	23
Cortex							
Vis. Sample	9.3***	-3.9	8.6**	0.3	3.3	8.8***	-2.1
Som. Sample	4.7**	-2.3	6.0*	3.6	3.6	5.4***	0.5
Rem. Dorsal	10.6**	2.5	8.9**	3.8	4.6	9.8***	3.1
Ventral	5.2	1.5	0.7	-2.7	-3.8*	2.9	-0.6
Total	7.6***	1.0	4.8**	0.4	0.5	6.2***	0.7
Rest of brain	4.0*	-1.5	0.7	-0.8	-1.0	2.4*	-1.2
Total brain	5.5**	-0.5	2.4	-0.3	-0.4	4.0***	-0.4
Adrenals	-15.5*	-7.6	-8.0	-2.0	-1.9	-11.8*	-4.9
Terminal Body Wt.	-2.9	-4.8	-15.0***	7.9**	-10.7***	-8.9***	-6.4**

* $P \leq .05$, ** $P \leq .01$, *** $P \leq .001$. The P values were determined by Duncan multiple range tests after analyses of variance.

[a] ECT = Environmental Complexity and Training

[b] PEI = Paired in Extreme Impoverishment

[c] SC = Social Control (Standard Colony)

Table 2

Differences in AChE Activity per Unit of Weight between Rats in Three Environments and those of Littermates Isolated in Extreme Impoverishment (IEI)

(Expressed as percentages of the IEI values)

	Exper. 1		Exper. 2			1 & 2	
	ECT[a]	PEI[b]	ECT[a]	PEI[b]	SC[c]	ECT[a]	PEI[b]
N	12	12	11	11	11	23	23
Cortex							
Vis. Sample	-8.2***	-0.3	-9.0***	-5.3**	-6.4**	-8.6***	-2.7**
Som. Sample	-2.4	-1.2	-1.8	-1.4	-2.1	-2.1*	-1.3
Rem. Dorsal	-3.4*	0.5	-3.8	-2.1	-3.3	-3.6**	-0.8
Ventral	0.4	-0.1	-2.4	1.2	1.8	-0.8	0.6
Total	-2.0	0.3	-3.8*	-0.9	-1.4	-3.0**	-0.4
Rest of Brain	-1.4	0.3	0.1	0.0	0.8	-0.7	0.1
Total Brain	-2.1	-0.1	-1.6	-0.4	0.1	-1.9*	-0.3

* $P \leq .05$, ** $P \leq .01$, *** $P \leq .001$. The P values were determined by Duncan multiple range tests after analyses of variance.

[a] ECT = Environmental Complexity and Training

[b] PEI = Paired in Extreme Impoverishment

[c] SC = Social Control (Standard Colony)

Table 3

Differences in Ratio of ChE to AChE Activity between Rats in Three Environments, and those of Littermates Isolated in Extreme Impoverishment (IEI)

(Expressed in percentages of the IEI values)

	Exper. 1		Exper. 2			1 & 2	
	ECT[a]	PEI[b]	ECT[a]	PEI[b]	SC[c]	ECT[a]	PEI[b]
N	12	12	11	11	11	23	23
Cortex							
Vis. Sample	8.9*	5.9	15.1**	4.0	14.5**	12.0***	4.9*
Som. Sample	1.7	1.1	5.2*	2.5	6.8**	3.3*	1.7
Rem. Dorsal	4.0*	-1.4	6.7*	1.8	5.5	5.4**	0.2
Ventral	0.0	1.4	4.1	-0.6	1.6	2.2	0.3
Total	2.5	0.4	6.6**	1.0	4.8*	4.6***	0.7
Rest of Brain	-2.2	-0.6	0.8	-0.8	0.1	-0.8	-0.7
Total Brain	-0.8	-0.3	2.4	-0.3	1.5	0.8	-0.3

* $P \leq .05$, ** $P \leq .01$, *** $P \leq .001$. The P values were determined by Duncan multiple range tests after analyses of variance.

[a] ECT = Environmental Complexity and Training

[b] PEI = Paired in Extreme Impoverishment

[c] SC = Social Control (Standard Colony)

Figure

Fig. 1 Cortical weights and acetylcholinesterase activity of impoverished-environment animals expressed as ratios of the corresponding values of their enriched-environment littermates. Three independent sets of experiments are shown: (a) Social Control (SC) vs Environmental Complexity and Training (ECT), (b) Isolation Conditions (IC) vs ECT, and (c) Isolation in Extreme Impoverishment (IEI) vs ECT. The number of littermate pairs in each comparison is given just below the designation of the group. To obtain each measure, the ratio of each impoverished animal to its enriched littermate was taken, and then the mean of the group was calculated. Whenever a ratio differs significantly from 1.00, the P value of the difference is shown at the end of the bar. Whenever two adjacent ratios differ significantly from each other, the P value is shown on the arrow between the bars. The significances of differences between the extreme values (SC/ECT vs IEI/ECT) are not given in the figure, but they exceed .01 in every case (see text).